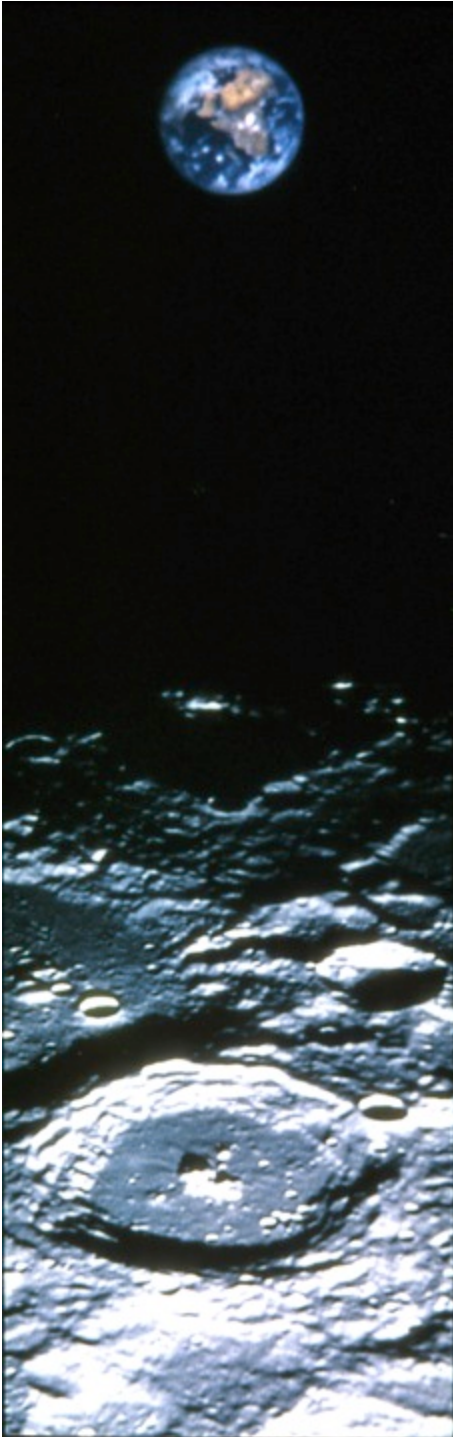




The Moon: Been there, done that?

Dr. Barbara Cohen

Barbara.A.Cohen@nasa.gov

NASA Marshall Space Flight Center

Huntsville AL 35812

The Moon - been there, done that?

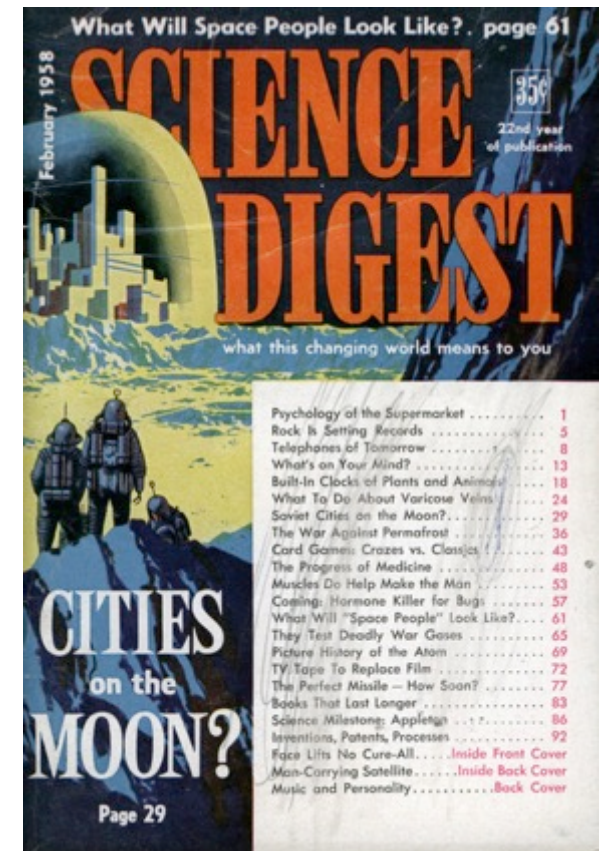


- Yes, we've been there – but we haven't done that!

Lunar Exploration
**We'll learn to
live and work on
another planet**



Lunar Science
**The Moon is a
window back in time
to understand how
all rocky worlds
formed and evolved**





Going back to the Moon for science

- Lunar science through Apollo 17 told us about commonality of planets and uniqueness of the Moon
- Now we have many questions about how planets work that can be answered on the Moon
- We know more about Mars than we do about the Moon in some ways!

	Mars	Moon
Best imaging resolution	20 cm/px (HiRISE on Mars Reconnaissance Orbiter, 2005)	50 cm/px (LROC on Lunar Reconnaissance Orbiter, 2009)
Robotic rovers	Pathfinder, Spirit, Opportunity, Curiosity	Russian Lunakhod-1 and Lunakhod-2
Landing site coverage	Global (east/west, equatorial/polar)	Limited (nearside equatorial only)



Moon Facts

- There is no air, liquid water or atmosphere
- Temperatures range from 100°C to -170°C
- There is little gravity compared to the Earth
- 3,476 km in diameter (little less than the distance across the United





Motions of the Moon

- The moon is considered a satellite because it revolves around the Earth
- It takes approximately 27.3 days to make a complete trip around the Earth
- The moon takes approximately 27.3 days to rotate on its axis
- What does this mean?
- This also means that we only





Phases of the Moon

- The moon itself does not give off any light – the only reason that we see the moon is because the light from the sun is reflecting off it
- The different shapes of the moon you see at night are because the moon goes through phases as it revolves around the Earth and the sun is hitting it at different angles





Eclipses

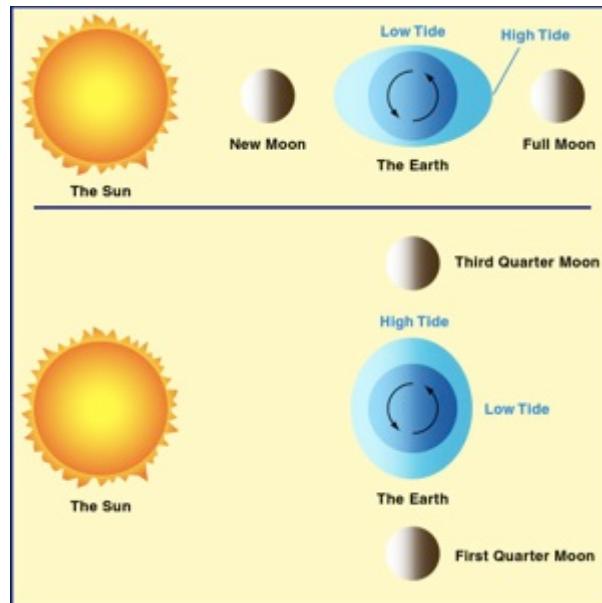
- Lunar eclipses are still rare, but not as rare as a solar eclipse
- A lunar eclipse occurs when the Earth passes between the sun and the moon – as a result the full moon will disappear in the sky until the moon, sun and Earth are no longer aligned



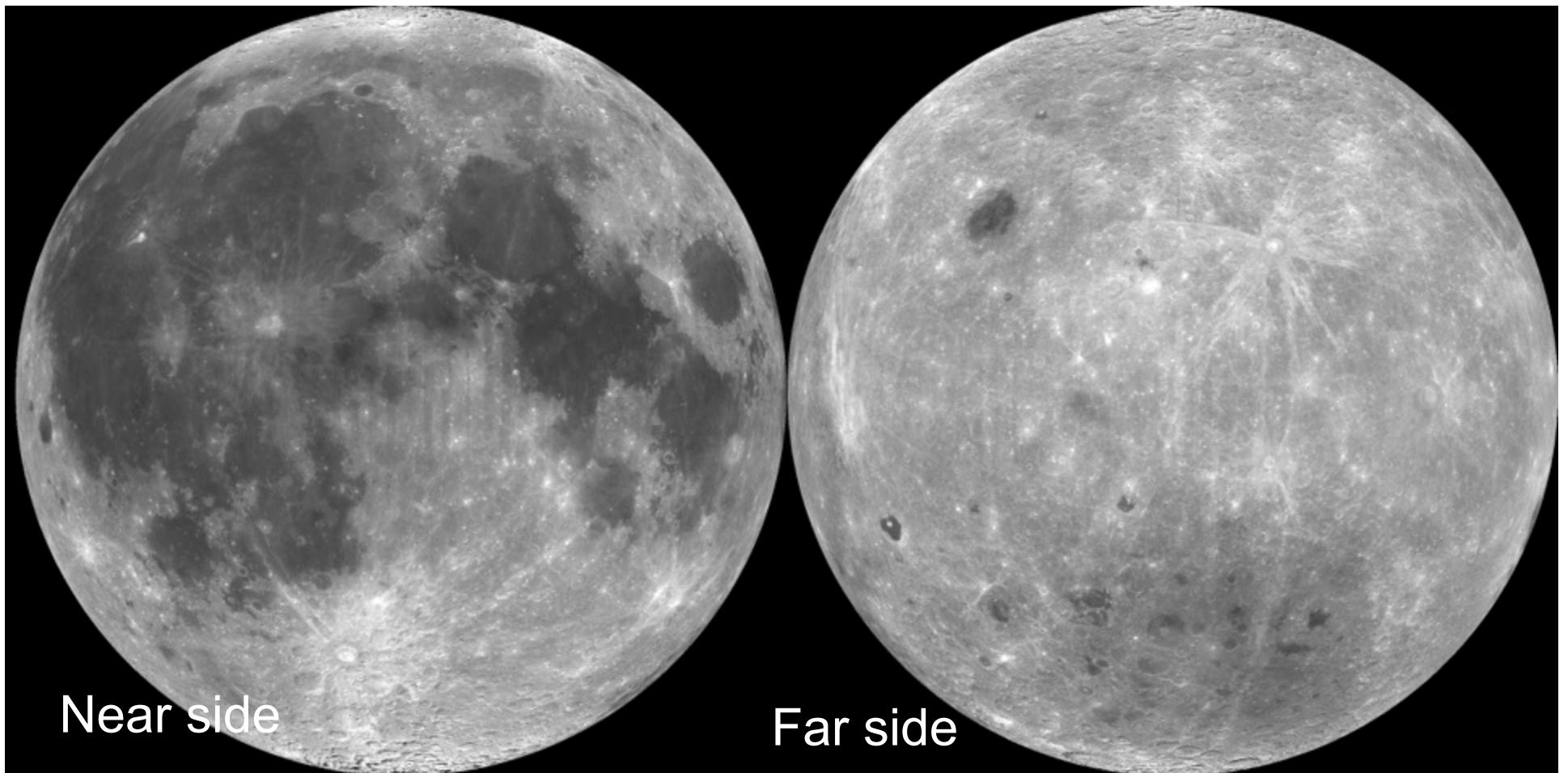


Tides

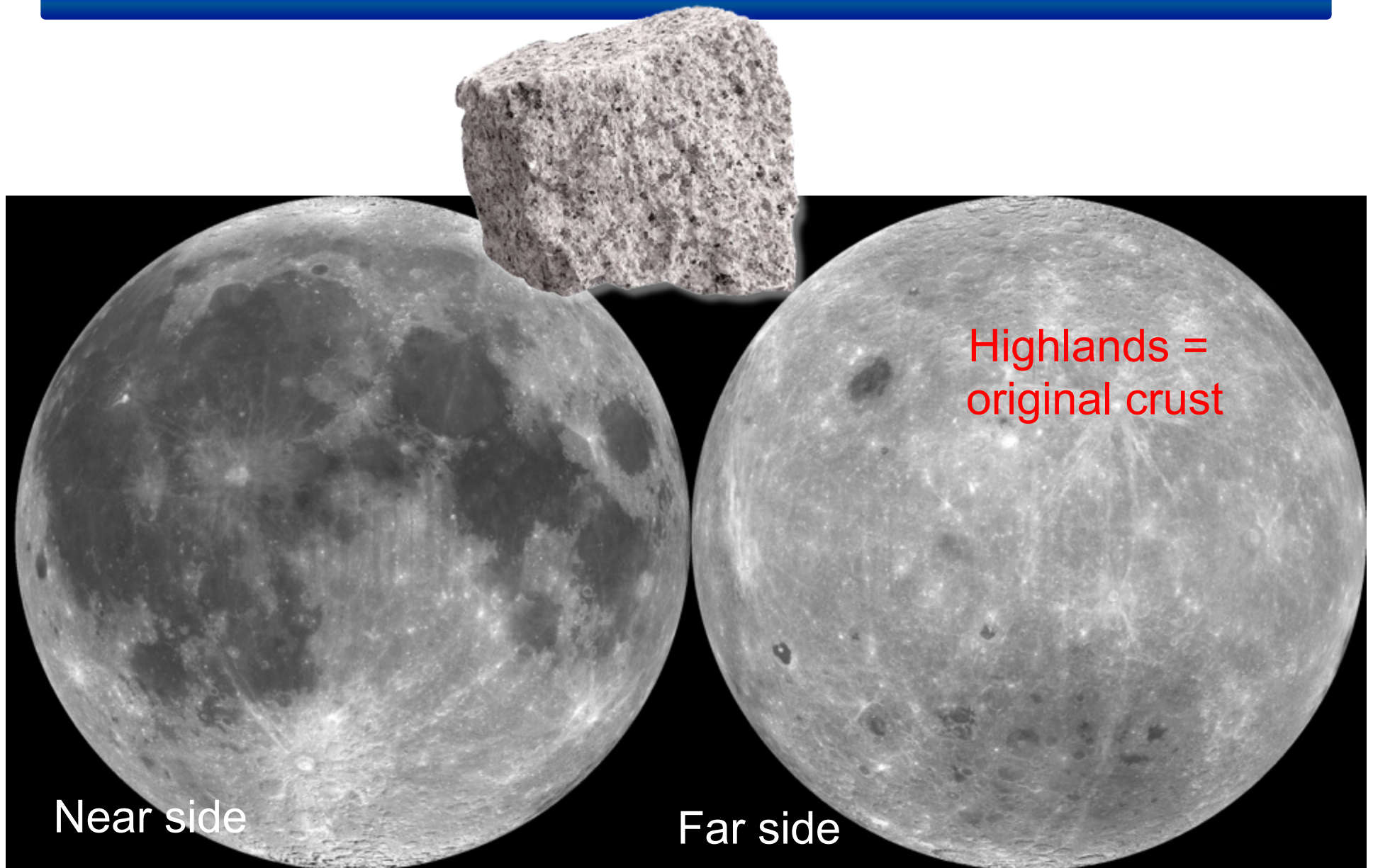
- Tides in the ocean occur because of the attraction of gravity between the Earth and moon
- Like the Earth revolving around the sun in a elliptical shape, the moon revolves around the Earth in an elliptical shape
- High tides occur when the moon and Earth are closer together and the attraction is stronger
- Low tide occurs when the moon and Earth are farther apart and the gravitational force is weaker



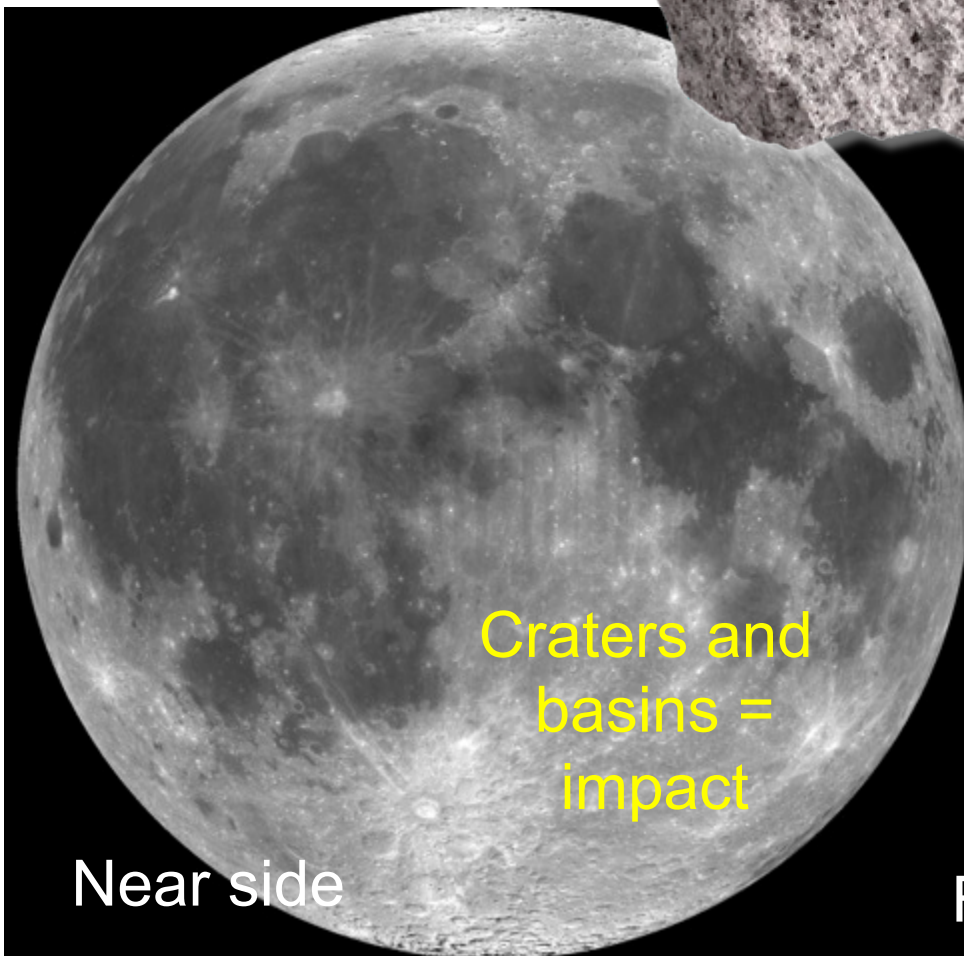
Geology of the Moon



Geology of the Moon

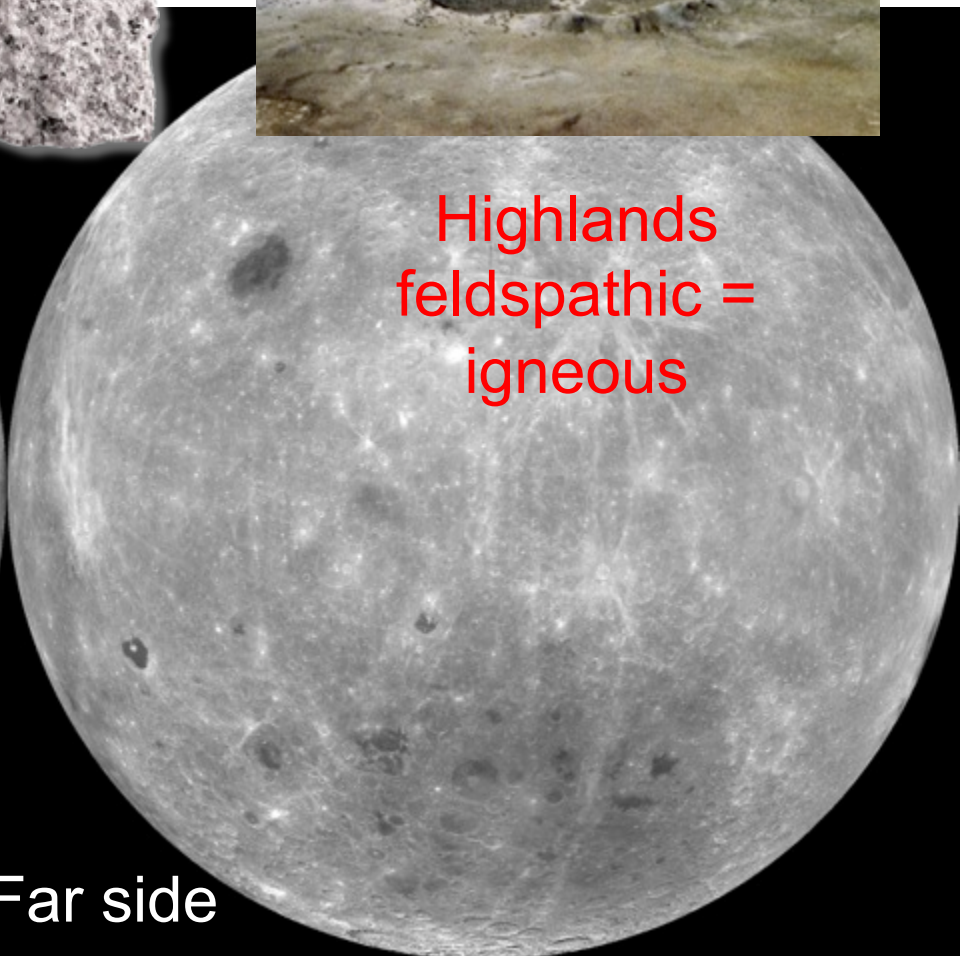


Geology of the Moon



Craters and
basins =
impact

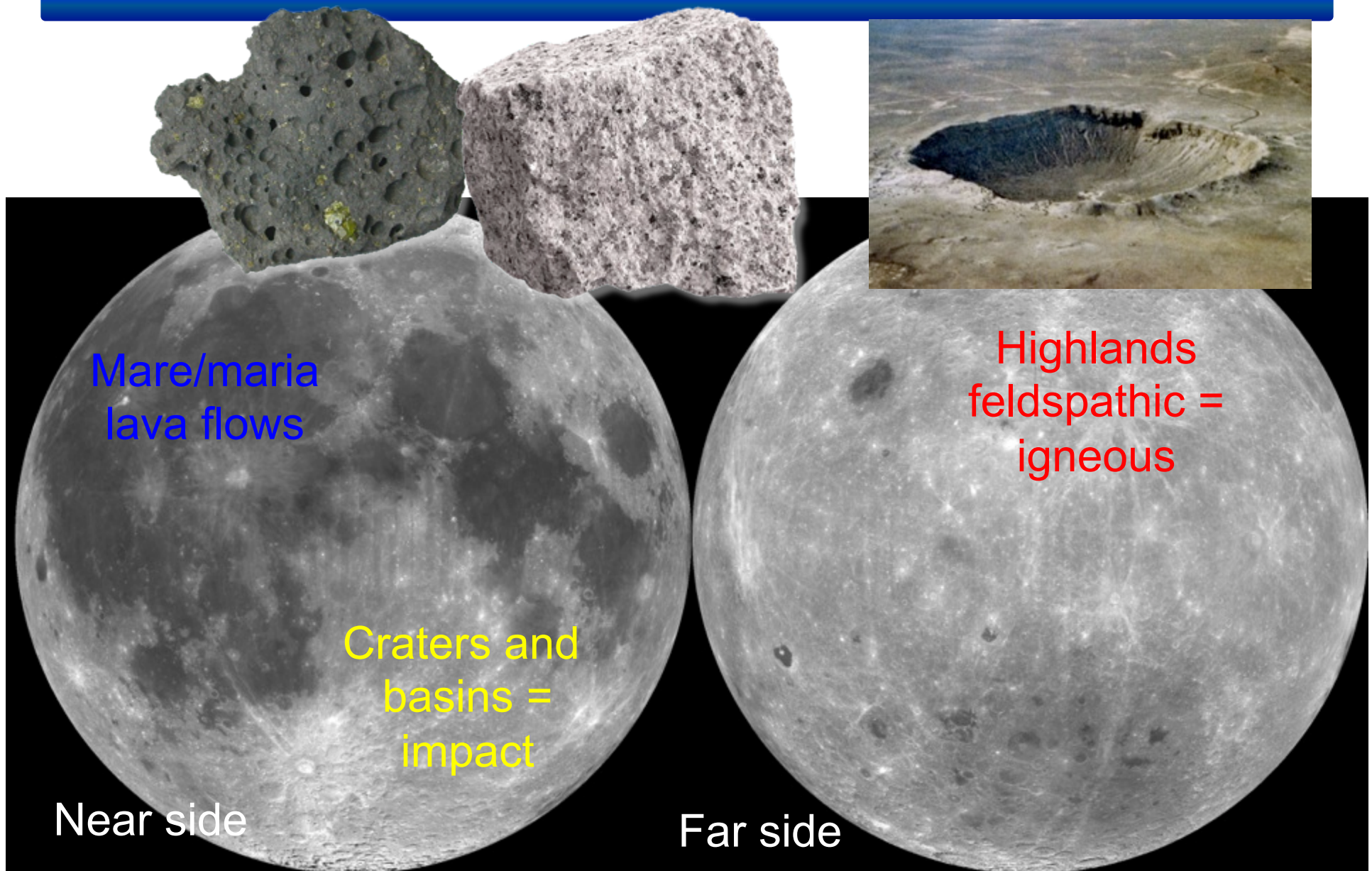
Near side



Highlands
feldspathic =
igneous

Far side

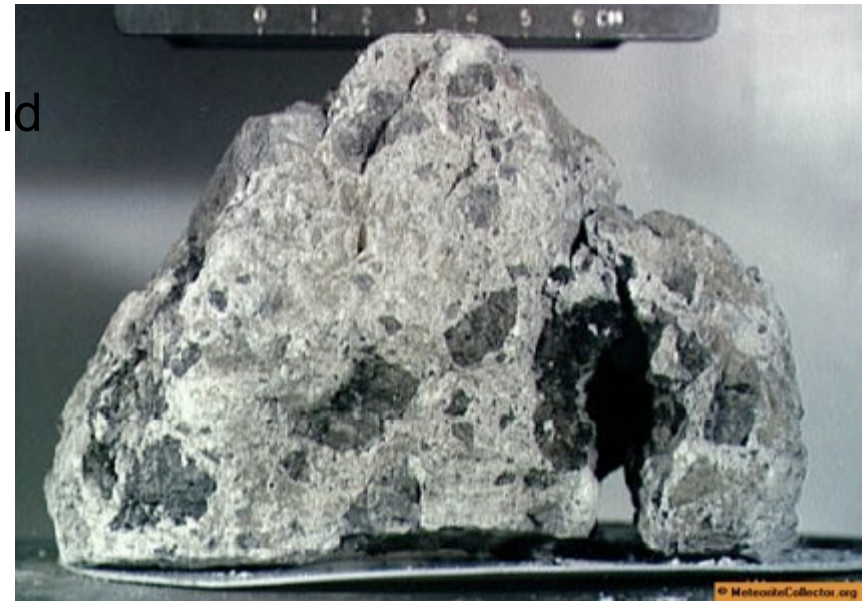
Geology of the Moon



Lunar rocks



Anorthosite
Igneous
Highlands crust
4.5 billion years old



Breccia
Sedimentary
Regolith (broken up layer)
0 - 4.5 billion years old

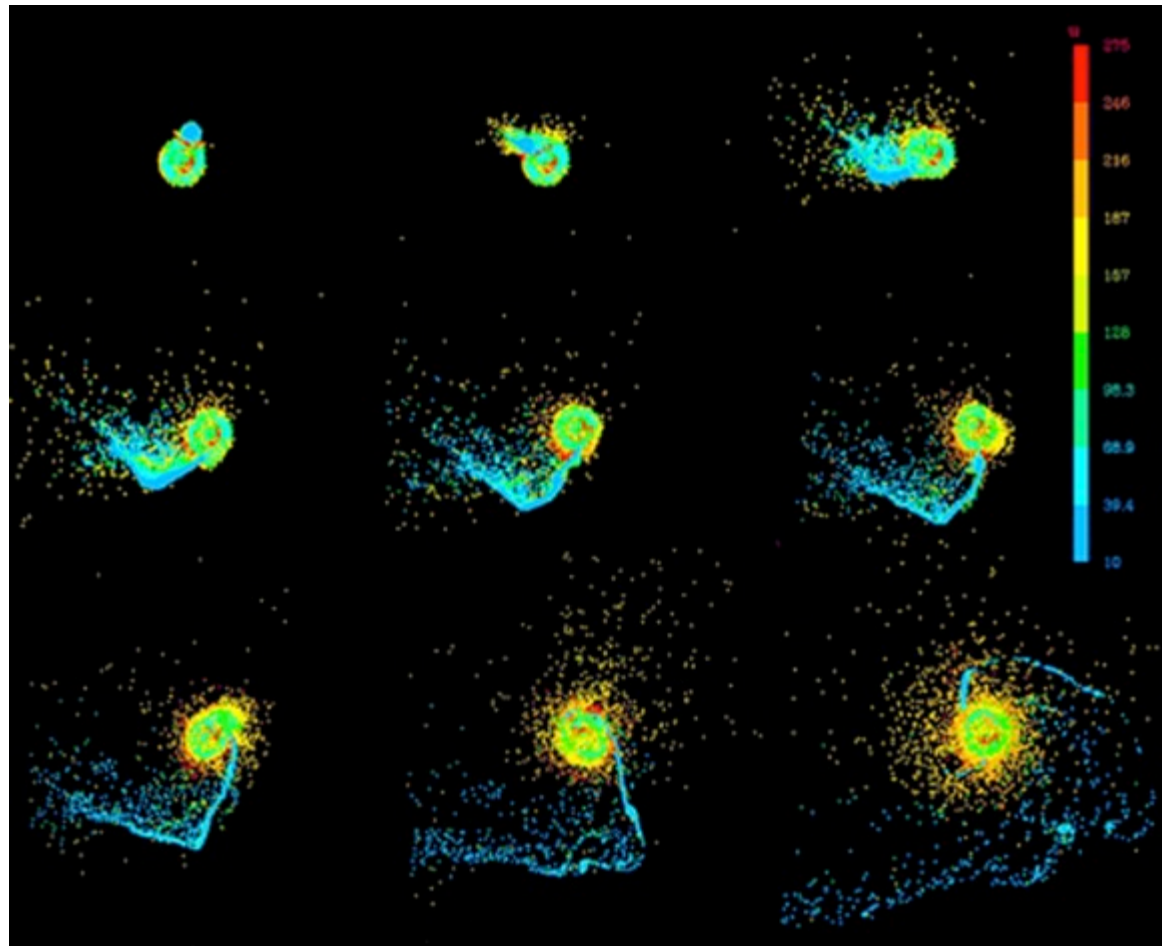


Basalt
Igneous
Mare (lava flows)
3.3 billion years old

Origin of the Earth-Moon system



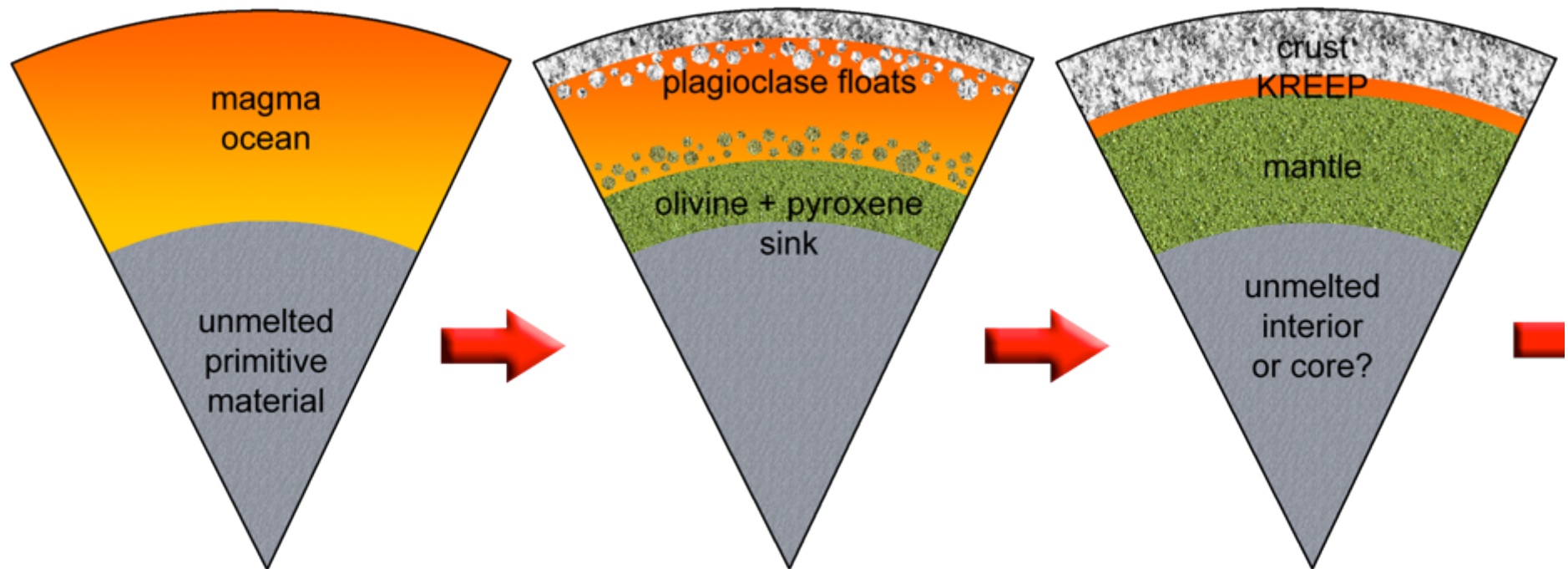
- Mars-sized body slammed into proto-Earth as the solar system as forming 4.5 billion years ago – no traces on Earth
- Moon formed out of hot crust/upper mantle





Crust, mantle, and core

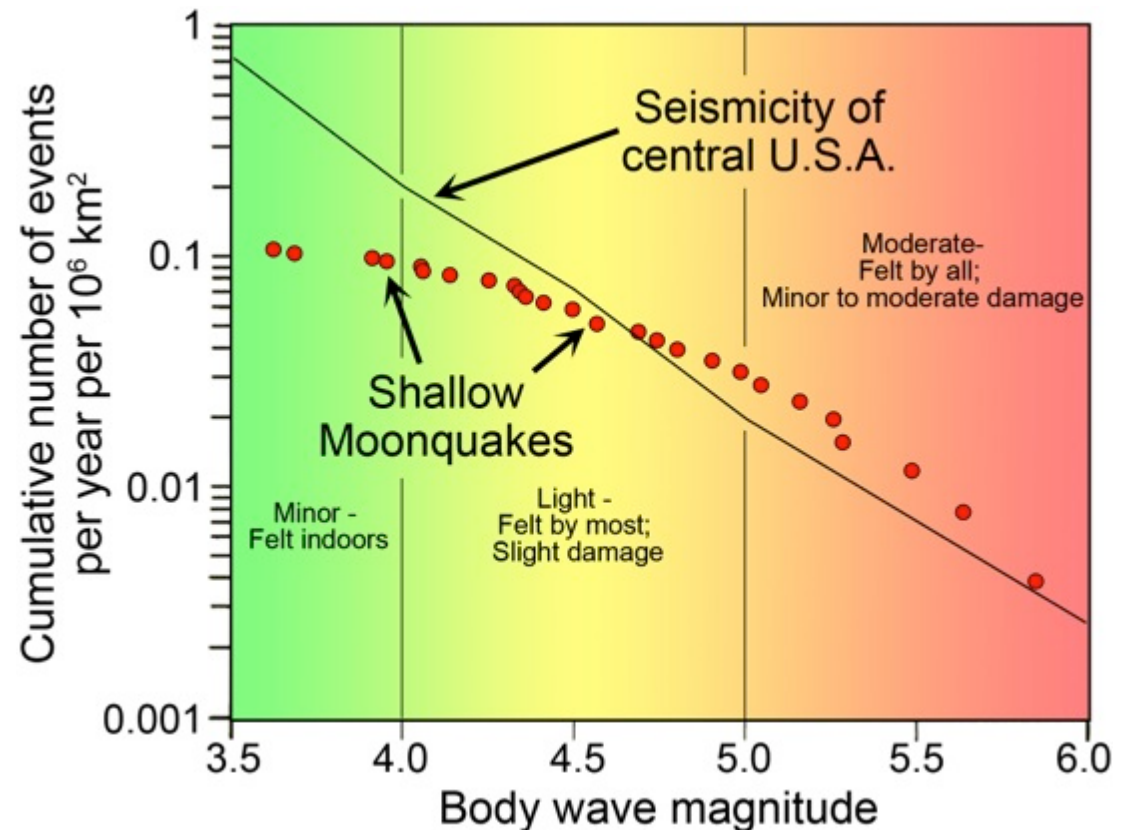
- The process of forming internal layers, or differentiation, is a common process on all planets
- When the moon formed, it formed like a planet
- In fact, it was the rocks from the Moon that made us think that all planets went through this same process!





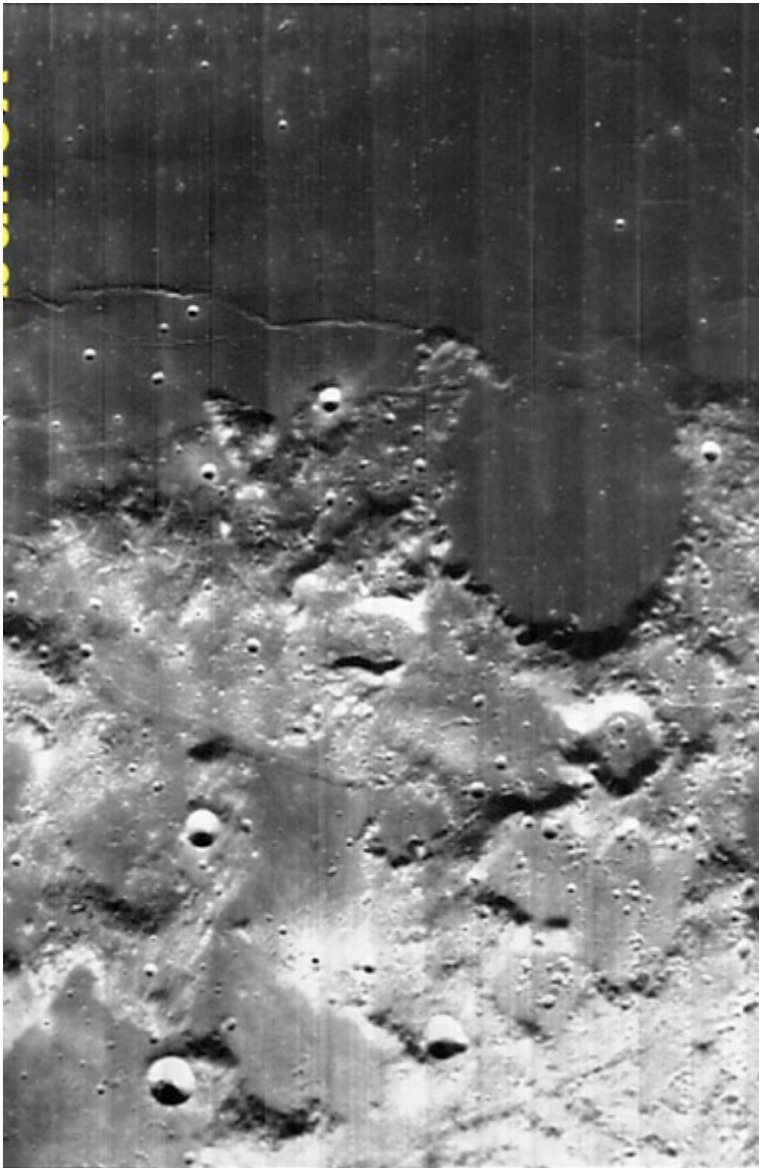
Active geology

- From 4.5 – 2 billion years, there were active volcanoes on the moon
- There aren't any volcanic cones, because the lava was very fluid and flowed out through cracks and into low-lying areas
- The Apollo samples contain small beads of volcanic glass that tell us there were giant fire-fountains on the moon
- The Apollo missions picked up thousands of earthquakes on the moon, or moonquakes!
- Moonquakes tell us that the moon is not geologically dead. It's still acting like a planet today.





Craters of the Moon

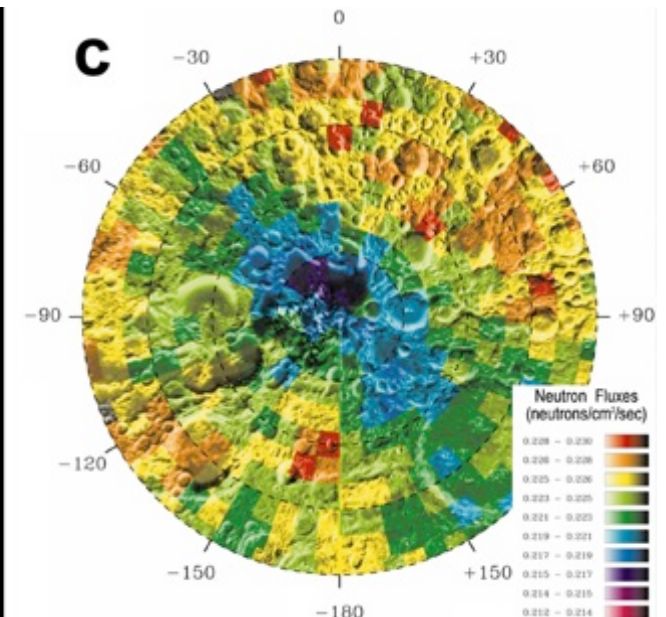
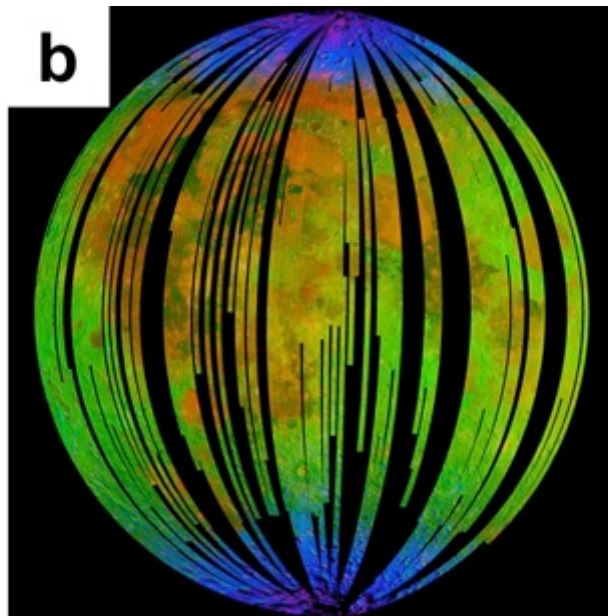
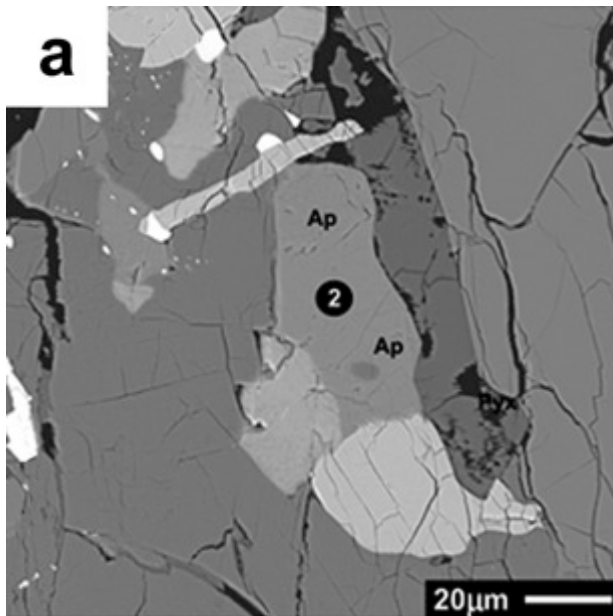


- The Moon preserves many impact craters on it
- all the craters you see on the moon (and there are hundreds of thousands of them!) had counterparts on the Earth at one point
- We don't see many impact craters on Earth today because the Earth's crust continually renews itself and erases old rocks and formations



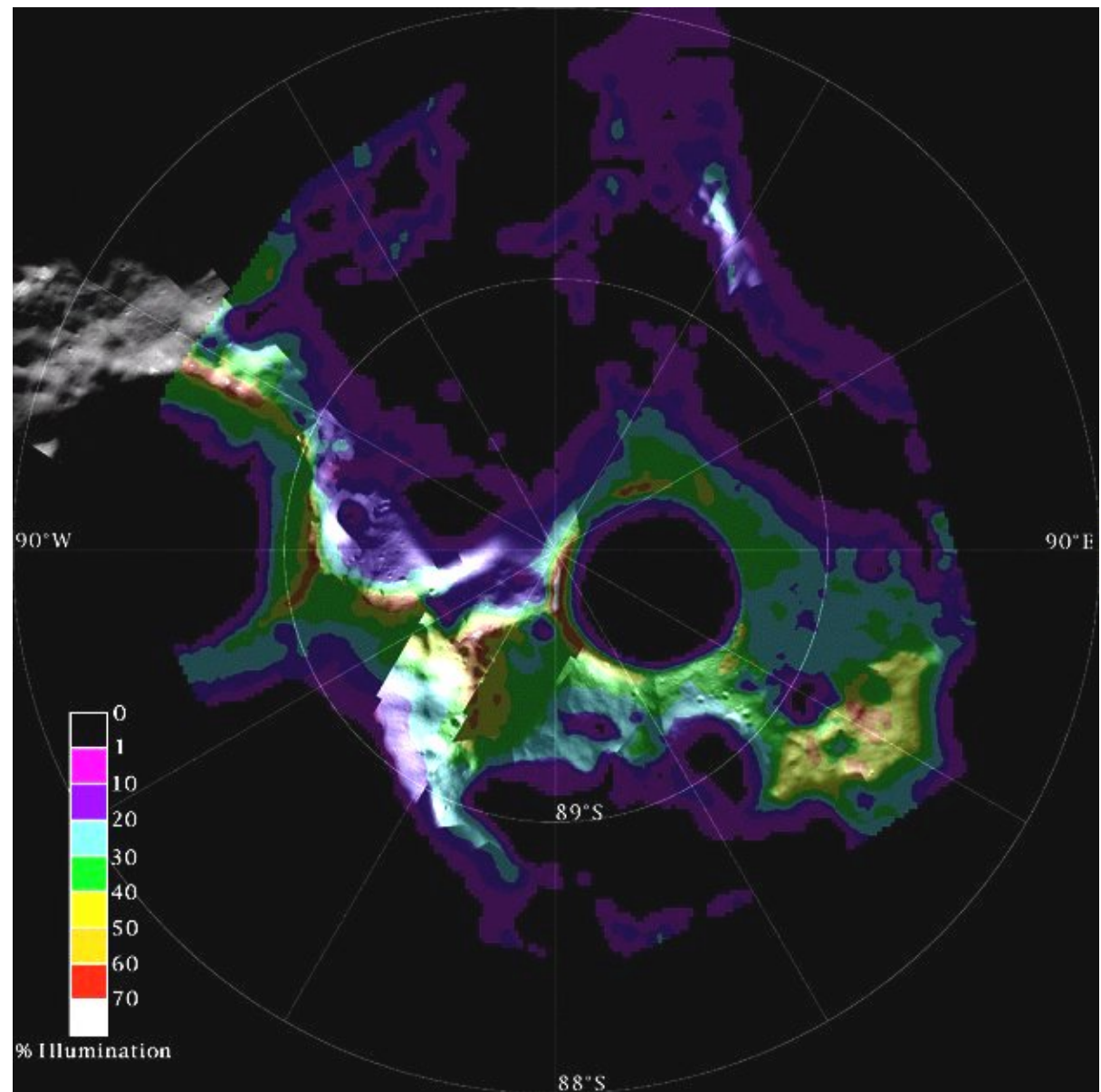
Water on the Moon

- Moon rocks are drier than any known terrestrial rock
- 3 kinds of lunar water:
 - a) Interior (magmatic) – in deep mantle rocks
 - b) Surficial (in upper mm of grains) – solar wind interaction
 - c) Polar deposits – H enhanced in shadowed areas as coherent blocks of water ice



Permanent sunlight and shadow

- Because of solar inclination angle, topography is important at the poles
- Some polar high points are in near-permanent sunlight
- Some polar crater floors are in permanent shadow – coldest places in the inner solar system (35K!)





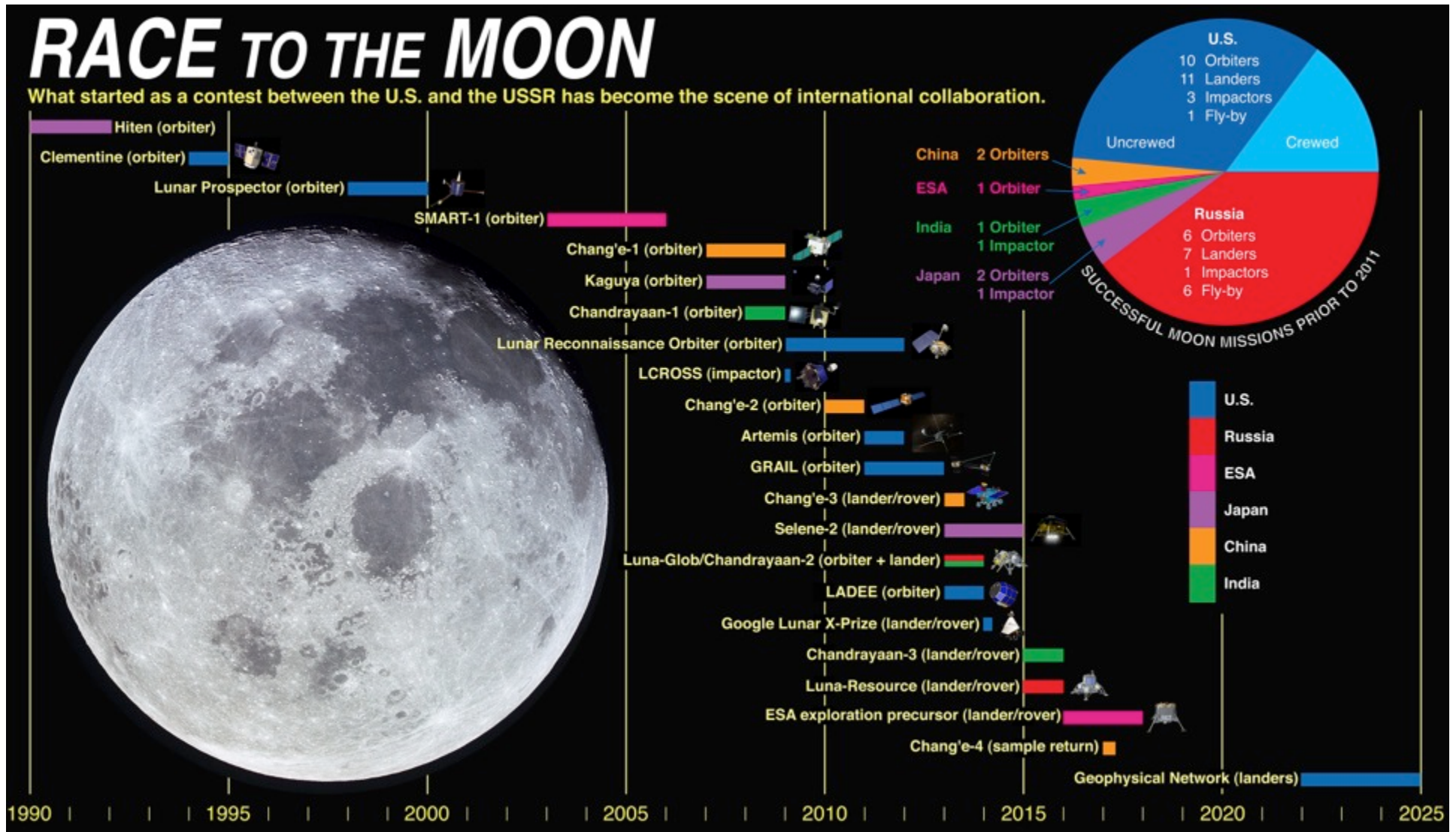
Exploring the Moon

- 1950s to 1960s – robotic landers (Ranger and Surveyor)
- Six Apollo missions (1969-1972)
 - 382 kg (842 lbs) rocks
- 12 Americans have walked on the moon
- USSR: Robotic landers, rovers, sample return missions
- Japan, India, China – robotic orbiters
- Lunar meteorites fall to the earth





Recent Robotic Lunar Exploration





Lunar Reconnaissance Orbiter (2009)

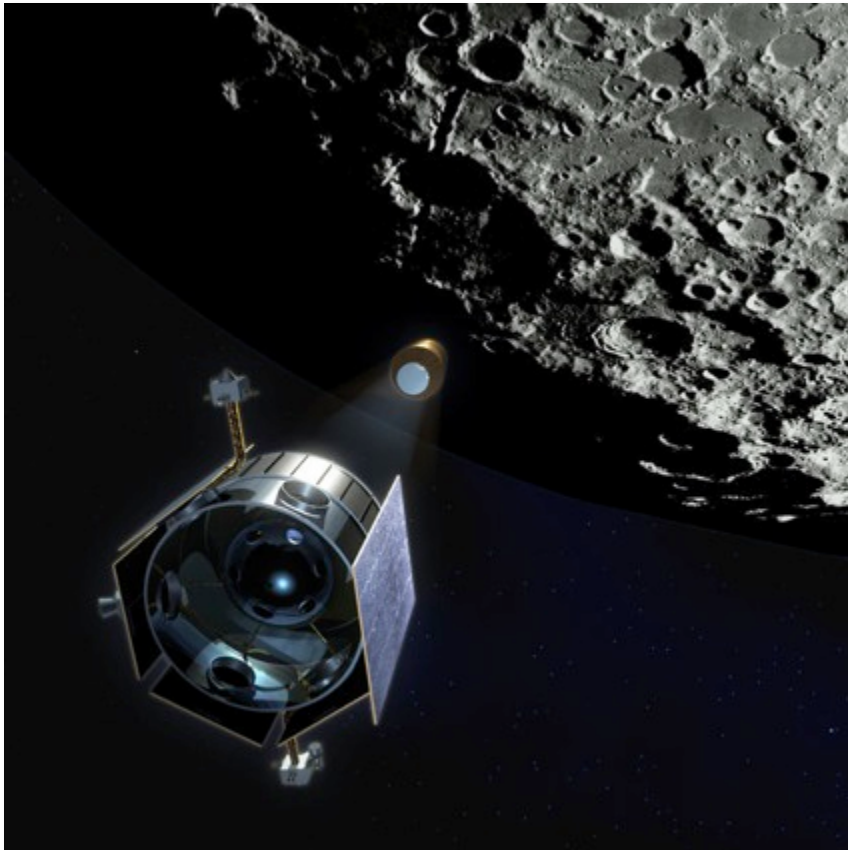
- Lunar Reconnaissance Orbiter (LRO) – initiated in 2004 under the Vision for Space Exploration
- Exploration Systems Mission Directorate (ESMD) – focus is on datasets to help plan human activities
- Goddard project, managed at MSFC
- **LRO Objectives:**
 - High-resolution imaging of the surface (50 cm / 20 inches) ✓
 - High resolution maps of the Moon's surface addressing topography, temperature, lighting, and radiation ✓
 - Assess the resources & environment of the Moon's polar regions ✓





LCROSS (2009)

- Lunar Crater Observation and Sensing Satellite, secondary payload on LRO vehicle, Ames project under LPRP management at MSFC
- Used the expended LRO Centaur upper stage as an impactor and flew through the plume with cameras and spectrometers



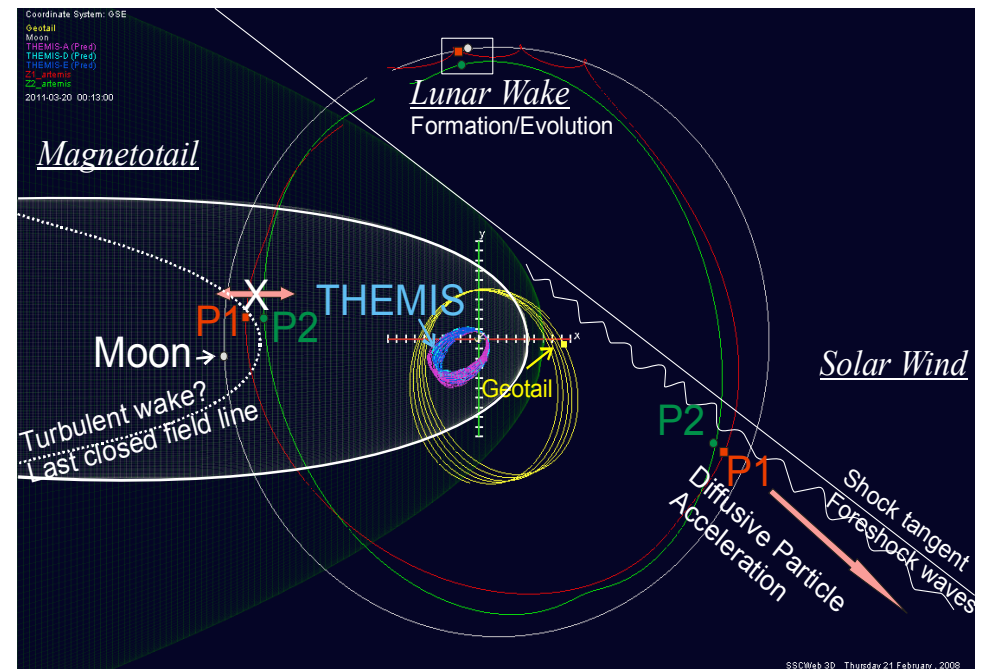
- **LCROSS Objectives:**

- Confirm the presence of water ice at a lunar pole
- Create an ejecta plume and analyze it for the presence of water (ice and vapor), hydrocarbons and hydrated materials

ARTEMIS (2010)



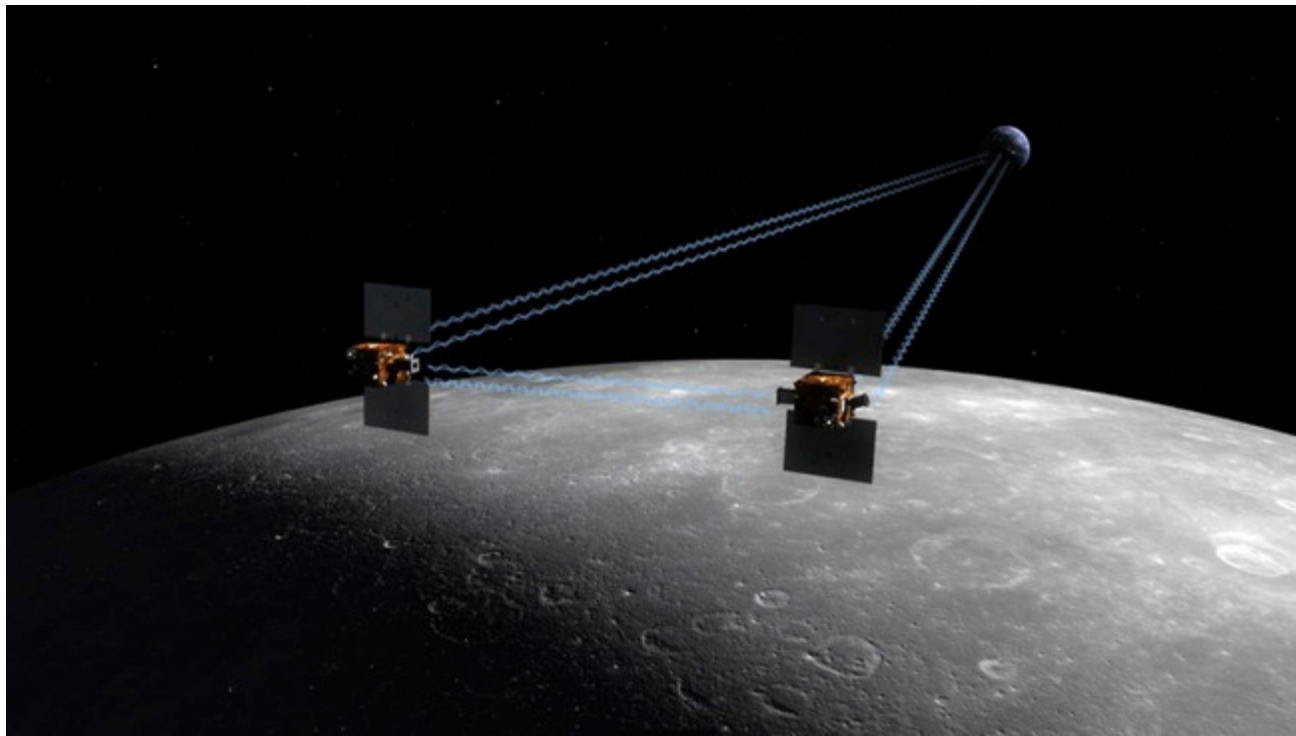
- Acceleration, Reconnection, Turbulence and Electrodynamics of Moon's Interaction with Sun
- Moves 2 Earth-observing THEMIS satellites into lunar orbits
- **ARTEMIS objectives:**
 - Study the lunar space environment, solar wind, magnetotail and lunar wake ✓





GRAIL (2011)

- Gravity Recovery and Interior Laboratory, an SMD PI-led mission by Dr. Maria Zuber at MIT, managed by Discovery program at MSFC
- Based on GRACE on the Earth - twin spacecraft with mutual ranging
- **GRAIL Objectives:**
 - Precisely map the gravity field of the Moon to recover information about the lunar interior structure and formation of the Moon ✓



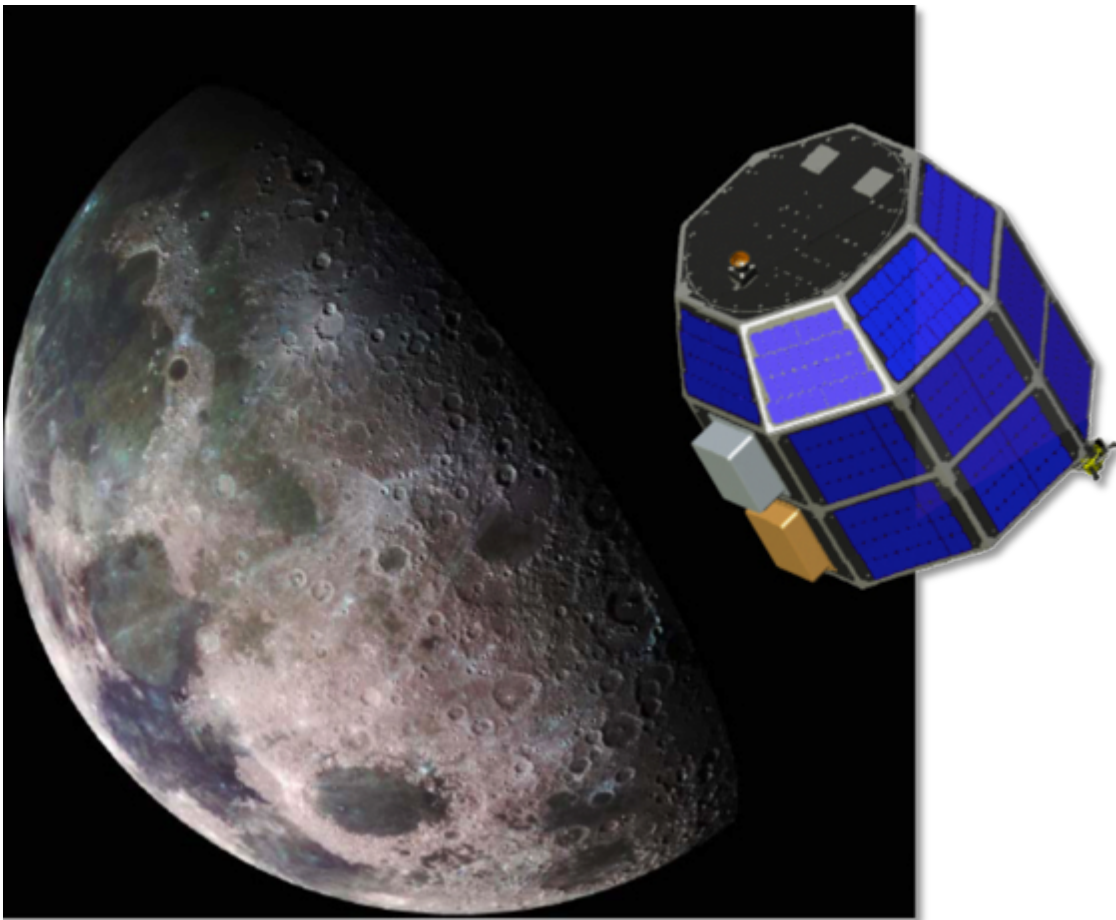


LADEE (2013)

- Lunar Atmosphere, Dust and Environment Explorer, Ames/GSFC project, managed by Lunar Quest Program at MSFC

- **LADEE objectives:**

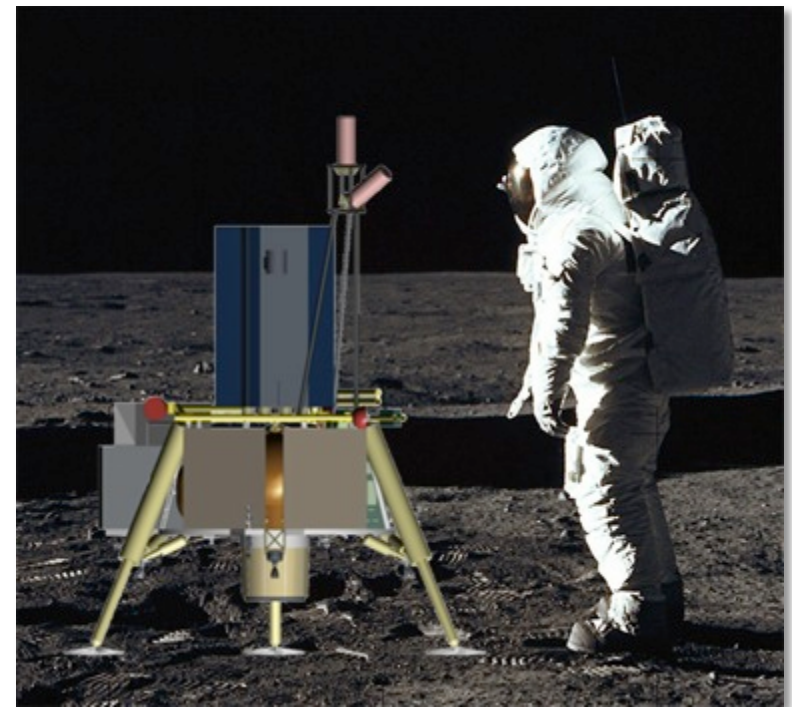
- Characterize the fragile lunar atmosphere before it is perturbed by further human activity
- Determine if Apollo astronaut sightings were Na glow or dust
- Document the dust environment to help guide engineering for the outpost and future robotic missions





Future Robotic Lander (2018?)

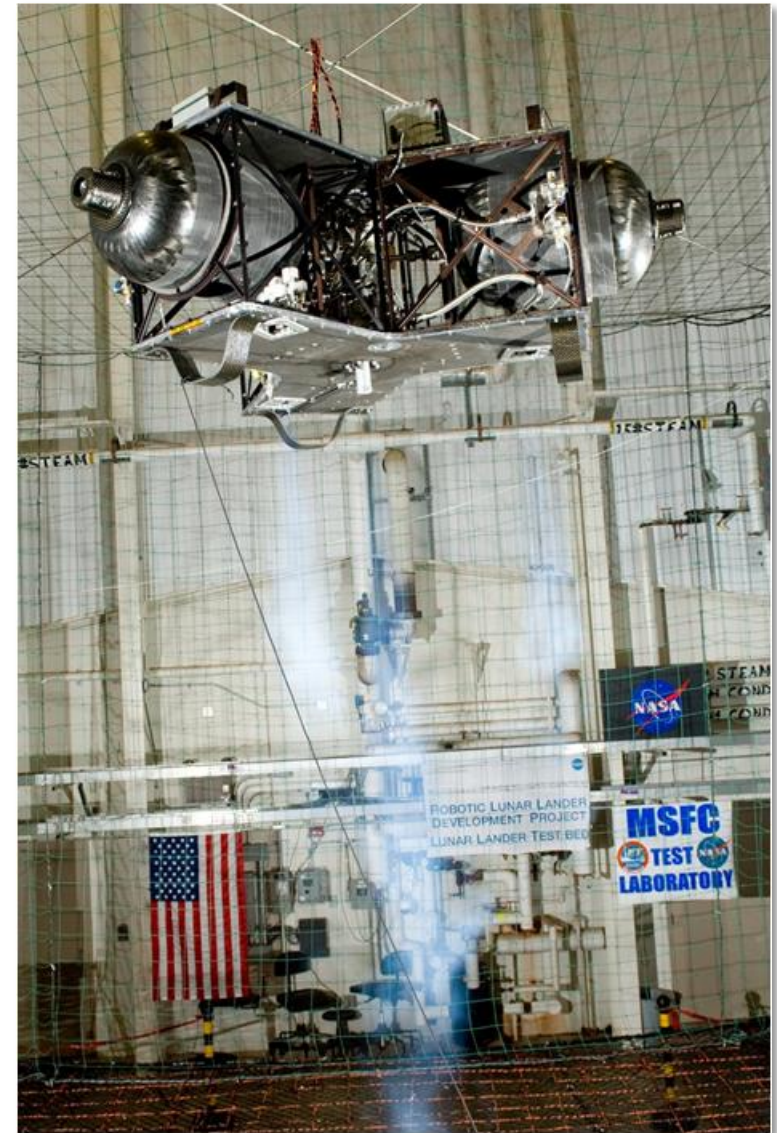
- Many high-priority science and exploration objectives are uniquely met by landed lunar missions
 - **Lunar Geophysical Network Mission:** Determine the composition and structure of the moon's interior
 - **Lunar Polar Volatiles Explorer:** In situ characterization of volatile species; understand current processes
 - **Lunar Sample Return:** Return rocks from unexplored sites, such as lunar farside or young lava flows, to terrestrial laboratories
 - **Human Exploration Precursors:** Characterize the lunar surface environment at landing sites: lighting, radiation, thermal, and dust; test technologies; demo ISRU



MSFC Lunar Lander work



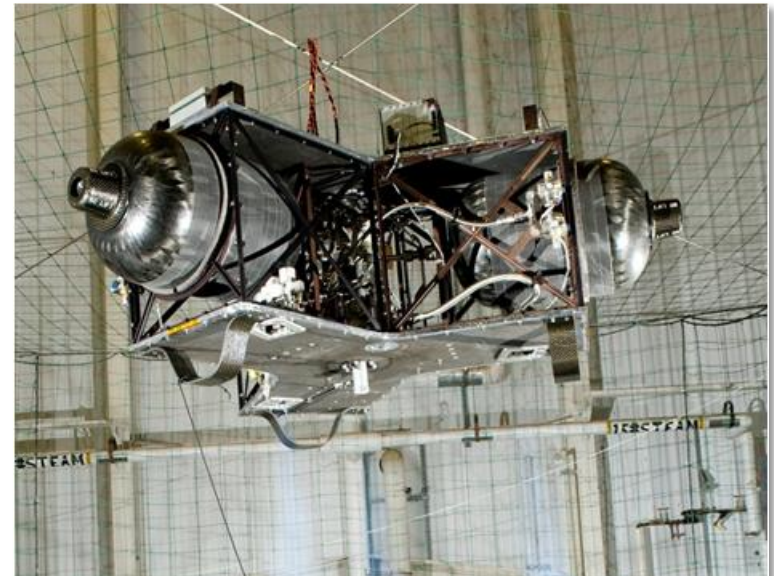
- **Cold-Gas Testbed**
 - First Flight September 2009; Over 150 successful flights
 - Mass: 107 kg dry / 146 kg wet
 - Approximately 10s of flight time
 - Compressed-air propulsion emulates flight system with pulsed operation



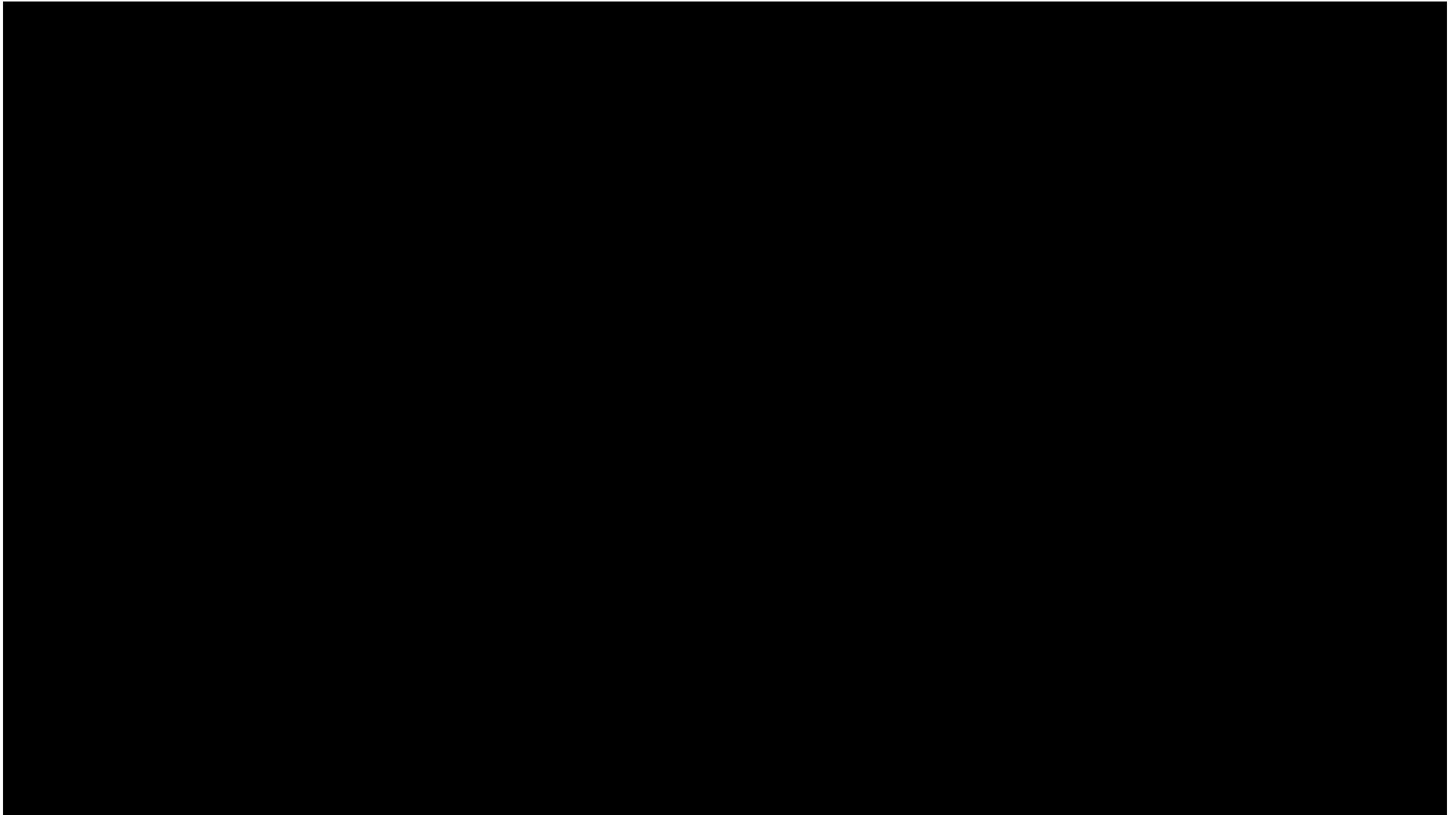


MSFC Lunar Lander work

- **Cold-Gas Testbed**
 - First Flight September 2009; Over 150 successful flights
 - Mass: 107 kg dry / 146 kg wet
 - Approximately 10s of flight time
 - Compressed-air propulsion emulates flight system with pulsed operation
- **Warm-Gas Testbed (Mighty Eagle)**
 - First flight June 2011; over 30 successful flights
 - Mass: 206 kg dry / 322 kg wet
 - About one minute of flight time
 - Hydrogen peroxide (90%) monopropellant propulsion system
 - Flight-like software and sensors



Mighty Eagle autonomous 100-ft flight (8/28/12)



Summary



Lunar science is planetary science!

Lunar samples teach us about the formation and evolution of the Moon, and the history of all the planets

The Moon is a cornerstone for all rocky planets, since it formed and evolved similarly to Earth, Mars, Mercury, Venus, and large asteroids

Lunar robotic missions provide important science and engineering objectives, and keep our eyes on the Moon

